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Predicting Rediated Noise With Power Flow Finite Element Analysis

D. Brennan
T.S. Koko
L. Jiang
J. Wallace
Martec Limited

Martec Limited
1888 Brunswick Street, Suite 400
Halifax, Nova Scotia
B3J 3J8

Martec Technical Report: TR-06-28
Contract Number: W7707-9-7214/001/HAL
Contract Scientific Authority: Layton Gilroy, 902-426-3100 x365

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Contract Report
DRDC Atlantic CR 2007-037
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Scientific Authority

Layton Gilroy

Approved by

David Hopkin

Head Signatures

Approved for release by

James L Kennedy

DRP Chair

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Abstract

The development and incorporation of the latest enhancements to the DRDC's PFFEA code are described. The purpose of this work was to make the modeling of the physical environment more realistic, while ensuring that the code runs as efficiently as possible. To this end a new high frequency radiated noise prediction capability has been added. This capability is based on algorithms developed for use in DRDC's AVAST acoustic modeling software tool. In addition to this, a series of upgrades have been made to the PFFFEA processors, PFGEN and POSTPF, in order to ensure compatibility with the latest version of the VASTF program. Finally, a series of validation studies, involving the prediction of the high frequency structural response of DRDC's ring stiffened test cylinder, are also presented.

Résumé

Le présent document décrit l'élaboration et l'intégration des plus récentes améliorations apportées au code PFFEA (de l'anglais « *Power Flow Finite Element Analysis* », *soit « analyse du débit de puissance par éléments finis » en français*) de RDDC. L'objectif de ces travaux était de rendre la modélisation de l'environnement physique plus réaliste, tout en s'assurant que le code fonctionne aussi efficacement que possible. À cette fin, une nouvelle capacité de prévision de l'émission de bruit haute fréquence a été ajoutée. Cette capacité est fondée sur des algorithmes mis au point pour une utilisation avec l'outil logiciel de modélisation acoustique AVAST de RDDC. De plus, une série d'améliorations ont été apportées aux processeurs PFFFEA, logiciel (programme) PFGEN et post-processeur POSTPF à des fins de compatibilité avec la dernière version du programme VASTF. Finalement, une série d'études de validation, comportant la prévision de la réponse structurale de cylindres d'essai à anneau renforcé de RDDC sont aussi présentées.

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Executive Summary

Introduction

Power flow finite element analysis (PFFEA) is a potentially powerful method for vibroacoustic analysis of structures. It uses vibrational conductivity modeling of structural components in which the flow of vibratory energy is treated in a way analogous to the flow of thermal energy in steady state. DRDC has over several years developed an in-house PFFEA capability to a stage at which relatively complex structural models can now be evaluated. The system has been tested on a variety of structural models including frames, stiffened and unstiffened plates and cylinders. When mature, this software will be capable of analyzing high frequency structural vibrations and interior noise in naval vessels and will be capable of predicting underwater radiated noise over a broad range of frequencies.

Results

In the current contract, the development and incorporation of the latest enhancements to the DRDC's PFFEA code are described. The purpose of this work was to make the modeling of the physical environment more realistic, while ensuring that the code runs as efficiently as possible. To this end a new high frequency radiated noise prediction capability has been added. This capability is based on algorithms developed for use in DRDC's AVAST acoustic modeling software tool. In addition, a series of upgrades have been made to the PFFEA processors, PFGEN and POSTPF, to insure compatibility with the latest version of the VASTF program. Finally, a series of validation studies, involving the prediction of the high frequency structural response of DRDC's ring stiffened test cylinder, are also presented.

Significance and future plans

The upgraded PFFEA code is now capable of predicting underwater radiated noise from structures at high frequencies for a limited set of structural configurations. This capability may be used to evaluate some signature components, but further effort is required to produce a general purpose tool. The PFFEA software must be upgraded to allow for more general structures to be analyzed and must be validated using experimental model- or full-scale data before it is available for general use.

Brennan, D.P., Koko, T.S., Jiang, L., Wallace, J.C. 2007. Predicting Radiated Noise With Power Flow Finite Element Analysis. DRDC Atlantic CR 2007-037. Defence R&D Canada - Atlantic.

Sommaire

Introduction

L’analyse par éléments finis du débit de puissance (PFFEA) est une méthode potentiellement puissante pour l’analyse vibroacoustique des structures. Elle utilise la modélisation de la conductivité vibrationnelle de composants structuraux dans lesquels le flux d’énergie vibratoire est traité d’une manière analogue au traitement du flux d’énergie thermique en régime stationnaire. RDDC a travaillé pendant plusieurs années à la mise au point d’une capacité de PFFEA dans ces installations de sorte qu’il est maintenant possible d’évaluer des modèles structuraux relativement complexes. Il s’agit d’un système qui a été mis à l’essai sur divers modèles structuraux, y compris les ossatures, cylindres et plaques renforcés et non renforcés. Lorsqu’il sera achevé, ce logiciel permettra l’analyse des vibrations structurales haute fréquence et du bruit à l’intérieur de bâtiments de guerre et permetra de prévoir le bruit émis sous l’eau à l’intérieur d’une grande plage de fréquence.

Résultats

La mise au point et l’intégration des plus récentes améliorations apportées au code PFFEA sont décrites dans le contrat en cours. L’objectif de ces travaux était de rendre plus réaliste la modélisation de l’environnement physique, tout en s’assurant que le code fonctionne aussi efficacement que possible. À cette fin, une nouvelle capacité de prévision de l’émission de bruit haute fréquence a été ajoutée. Cette capacité est fondée sur des algorithmes mis au point pour une utilisation avec l’outil logiciel de modélisation acoustique AVAST de RDDC. De plus, une série d’améliorations ont été apportées aux processeurs PFFEA, logiciel (programme) PFGEN et post-processeur POSTPF à des fins de compatibilité avec la dernière version du programme VASTF. Finalement, une série d’études de validation, comportant la prévision de la réponse structurale de cylindres d’essai à anneau renforcé de RDDC sont aussi présentées.

Portée et recherches futures

Le code PFFEA amélioré permet actuellement de prédire le bruit émis sous l’eau par des structures à de hautes fréquences pour un ensemble limité de configurations structurales. Cette capacité peut servir à évaluer certaines composantes de la signature, mais un effort plus poussé est requis pour produire un outil à usage général. Le logiciel PFFEA doit être amélioré pour permettre l’analyse de structures plus générales et doit être validé au moyen d’un modèle expérimental – ou au moyen de données à l’échelle réelle avant qu’il ne soit disponible pour une utilisation générale.

Brennan, D.P., Koko, T.S., Jiang, L., Wallace, J.C. 2007. Predicting Radiated Noise With Power Flow Finite Element Analysis. DRDC Atlantic CR 2007-037. Defence R&D Canada - Atlantic.

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1. Introduction

Power flow finite element analysis (PFFEA) is a new and potentially powerful method for vibroacoustic analysis of structures. It uses vibrational conductivity modeling of structural components in which the flow of vibratory energy is treated in a way analogous to the flow of thermal energy in steady state. DRDC has over several years developed an in-house PFFEA capability to a stage at which relatively complex structural models can now be evaluated. The system has been tested on a variety of structural models including frames, stiffened and unstiffened plates and cylinders. This work is an extension of the PFFEA software developed in previous contracts including “Enhancement of the Software for PFFEA Modeling and Analysis of Ship Structures” and “Verification and Extended Application of the Power Flow Finite Element Analysis Software” which led to the present state of the PFFEA suite of computer codes. This work has in part motivated the development of VASTF, a finite element program for problems governed by second-order field-type equations.

In the current contract, a methodology identified for prediction of radiated sound at high frequency has been developed. Further validation studies have also been performed on a decked cylindrical model and the PFFEA processors, PFGEN and POSTPF, has been upgraded to ensure full compatibility with the latest version of the VASTF program.

2. Comparison of PFFEA Software to Experimental Data from Ring Stiffened Cylinder

2.1 SNAP Model

Figure 2.1 provides an illustration of the actual cylinder model used in the experimental trials [1] and Figure 2.2 shows the SNAP model used in the analysis. The model was created in Trident FEA and modified in order to be consistent with the current SNAP input file format. Only one half of the structure was modeled in order to take advantage of symmetry and reduce modeling and computational costs. The model is comprised of 30 components, which are shown colour coded in Figure 2.2. A listing of the components and the parts they represent are also presented in Table 2.1. In order to simplify the modeling of junctions, the stiffened plate structure of the deck was smeared into an equivalent un-stiffened plate structure, with the thickness and material density values modified. The modifications were done in such a way that the mass/weight of the equivalent plate structure was the same as that of the stiffened deck structure, and the thickness and material density were adjusted to ensure that the equivalent plate had similar frequency response as the stiffened deck structure. This exercise was carried out in Trident FEA, using all round clamped models of the stiffened deck and equivalent un-stiffened plate structures. Table 2.2 shows the dimensions and properties of the equivalent plate as well as the original stiffened plate deck structure. The first five modal frequencies obtained for the equivalent plate are compared to those obtained for the original stiffened plate structure in Table 2.3. Table 2.3 shows that the frequency response of the equivalent plate closely matches that of the original stiffened plate structure, confirming that the equivalent plate model provides a good representation of the original stiffened plate deck structure. The input power (or load) was applied at top point of the stiffener between shell 2 and shell 3 (see Figure 2.1). A material loss factor of 0.02 was used in all the analysis cases.

2.2 Results

The response of the stiffened cylindrical shell structure at various forcing frequencies was computed using the SNAP software tool. Figure 2.3 shows the frequency dependent transfer mobility response in the shell (components 2, 3 and 4, which correspond to shell Nos. 1, 2, and 3 in Figure 2.1). It is seen that the SNAP responses for shell nos. 1, 2 and 3 are very close for all forcing frequency values. In Figure 2.4 the SNAP transfer mobility responses in the shell components are compared to the experimental results. For the SNAP analysis, only the case for shell 2 is shown, since the responses for shell 1 and 3 are very similar. The SNAP results were closest to the experimental results for shell 1, with the error varying from 3% at 10 kHz to 23% at 2 kHz. For shells 2 and 3, the predicted SNAP responses had errors varying from 15%

at 8 kHz to about 28% at 2 kHz and 12 kHz. In the experimental program, results were presented for the ring stiffeners. However, these were not available in the SNAP analysis, due to the fact that the stiffeners were modeled as beams, which are considerably stiffener than the shell, and tend to block the energy flow. In order to obtain results in the stiffeners, it would be necessary to model the beams as shell elements. It is expected that such an analysis would lead to better predictions of the energy flow in the shell, thereby resulting in reductions in the modeling errors stated above. It is therefore suggested that such an analysis be carried out in future. Also, the treatment of shell-beam junctions in SNAP should be investigated further to improve the treatment of such junctions.

Figure 2.5 shows the SNAP and experimental responses of the deck structure. The SNAP predictions for the deck structure are much closer to the experimental results than for the shell. At 6 kHz, 8 kHz and 11 kHz forcing frequencies, the SNAP and experimental responses are virtually identical. The errors at the other forcing frequencies were no more than 14%. This further confirms that the larger errors in the shell, as discussed above, might be due to the treatment of shell-beam junctions in the SNAP model. Figures 2.6a and 2.6b show the SNAP spatial variation of the transfer mobility responses in the shell and deck, respectively. Recall that the load was applied at the interface between shells 2 and 3. The responses tend to peak in the second component and reduce gradually away from this component.

Table 2.1 Description of Components

Component No.	Description
1, 8	End caps
2-7	Bottom part of shell (below deck)
9-14	Top part of shell (above deck)
15-19	Stiffeners above deck
20-24	Stiffeners below deck
25-30	Deck

Table 2.2 Properties of Equivalent Un-stiffened Plate Deck Structure

Property	Original Stiffened Plate Deck	Equivalent Plate Deck
Length (m)	2.75	2.75
Width (m)	0.624	0.624
Thickness (m)	0.01	0.014
Density (kg/m^3)	7810	3350
Total mass (kg)	80.5	80.5
Young's Modulus (Gpa)	207	207
Poisson's Ratio	0.3	0.3

Table 2.3 Comparison of Natural Frequencies

Mode No.	Natural Frequencies (Hz)	
	Original Stiffened Plate Deck	Equivalent Plate Deck
1	305.1	350.2
2	329.5	363.2
3	389.3	387.9
4	482.7	428.5
5	555.2	488.2

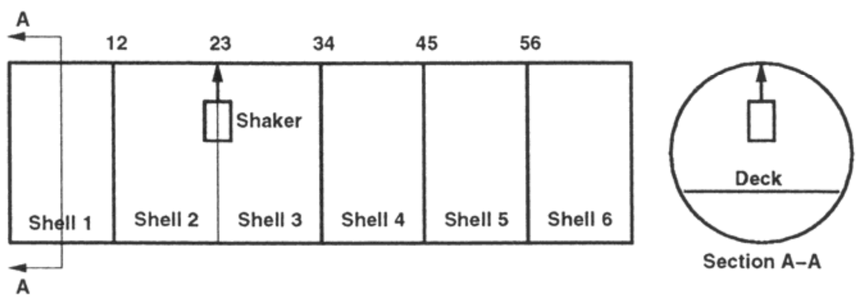


Figure 2.1 Decked Cylinder Model Showing Shell and Shaker Locations (Reproduced from Gilroy)

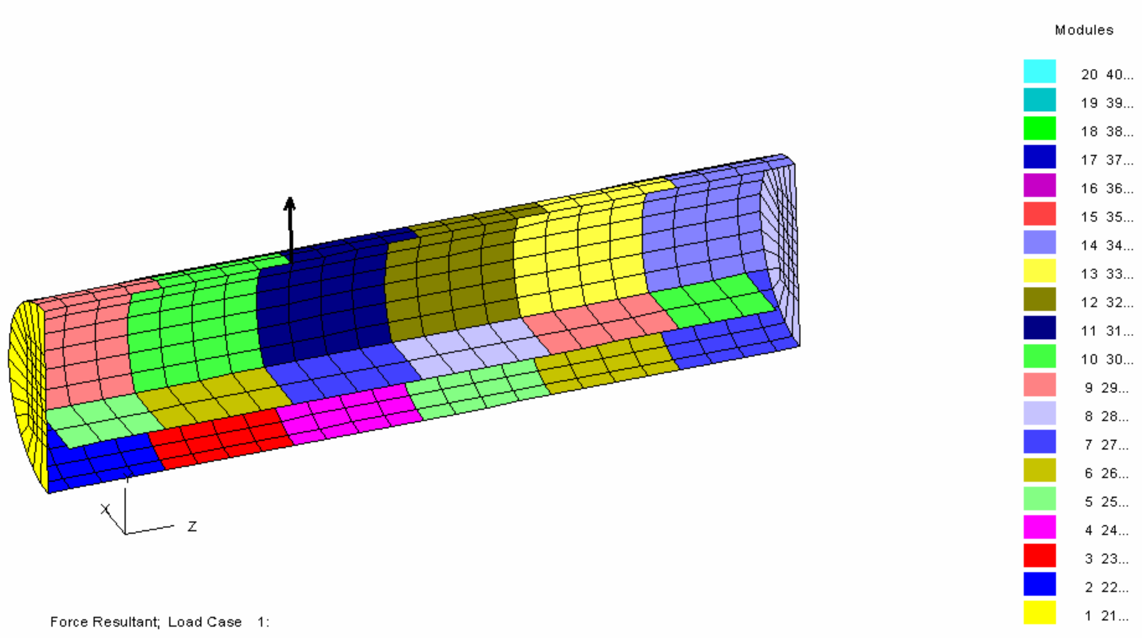


Figure 2.2 Snap Model

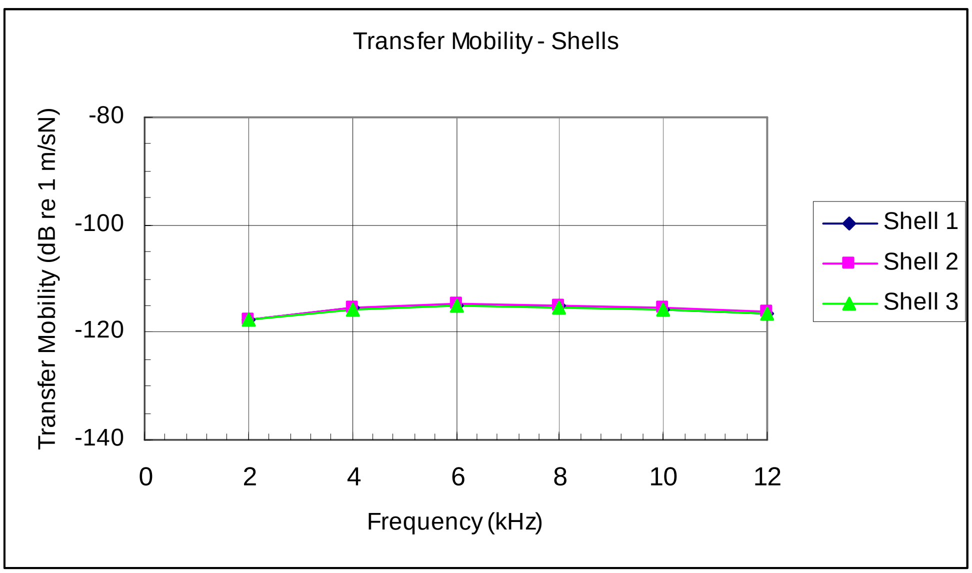


Figure 2.3 SNAP Predictions of Transfer Mobility in Shell

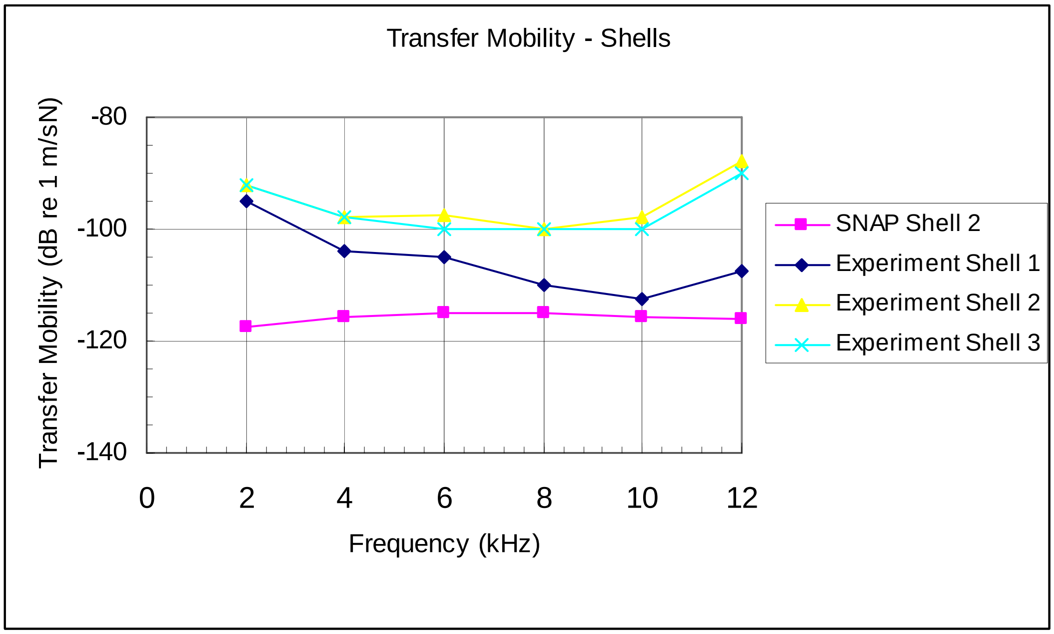


Figure 2.4 Comparison of SNAP and Experimental Predictions of Transfer Mobility in Shell

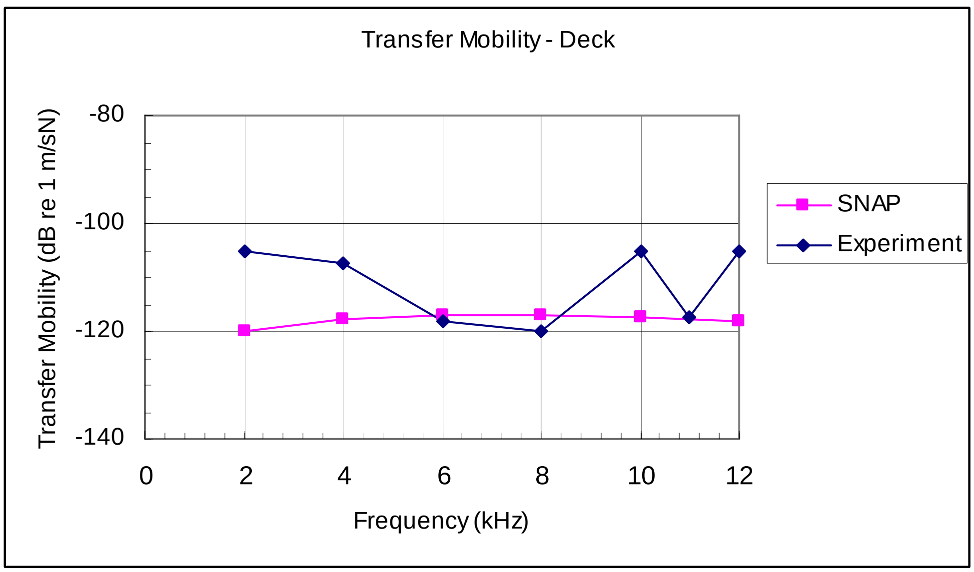
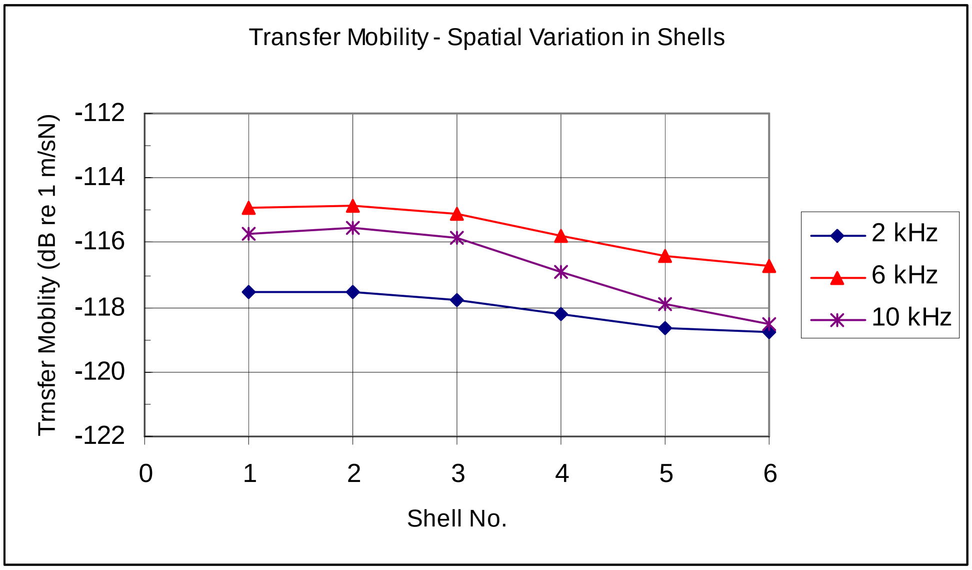
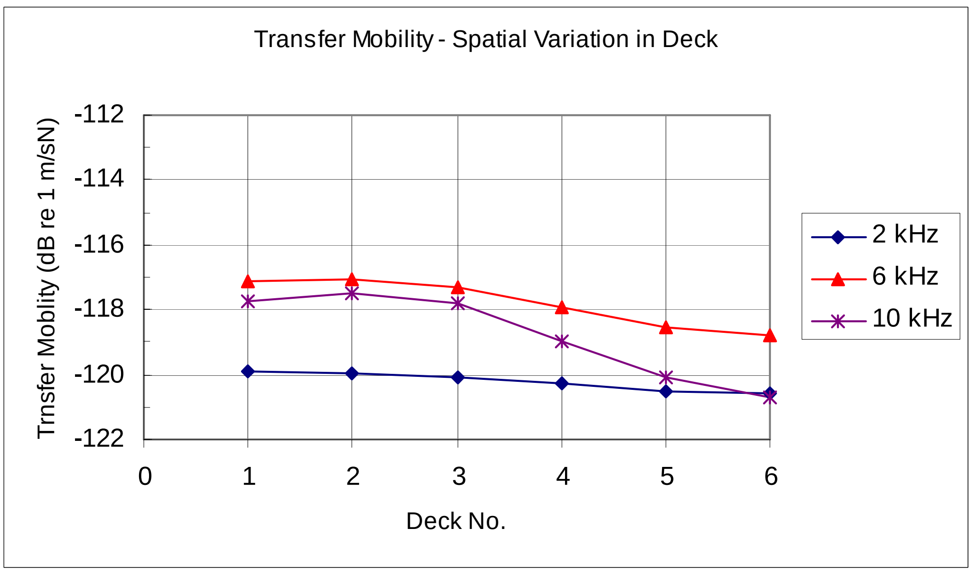


Figure 2.5 Comparison of SNAP and Experimental Predictions of Transfer Mobility in Deck



(a)



(b)

Figure 2.6 Spatial Variation of Transfer Mobility in (a) Shell; (b) Deck

3. Upgrade the PFFEA processors

The pre- and post-processors of the PFFEA program, namely PFGEN and POSTPF, were upgraded for compatibility with the latest version of the VASTF program, VASTF88. In this development, all the changes on the format of the input ASCII files and the output binary files from a previous version of VASTF, VASTF61, and the current version of VASTF, VASTF88, were first reviewed. Multiple changes in data sections related to element definition and convection boundary conditions were identified. The source code of the PFGEN and POSTPF programs was then studied and all the modules involved in the generation of input data for VASTF and extraction of VASTF results were isolated. The format statements in these models were then carefully checked against the changes on the data format identified earlier, and all the inconsistencies were corrected.

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4. Implement a Radiated Noise Capability for the PFFEA Software

For the past several years, Martec Limited, under contract to DREA, has been involved in the development of a new numerical technique known as Power Flow Finite Element Analysis (PFFEA) for evaluating high frequency vibrational and acoustic characteristics of ship structures. This work has formed part of Martec's collaboration with DRDC in the Ship Noise Project, and it has motivated the development of the VASTF finite element program.

PFFEA is similar to statistical energy analysis (SEA), in that the energy transferred between components is proportional to the difference in the energy densities of the components. The main difference lies in the fact in SEA each component is modeled by a single response variable, as opposed to the spatially varying response distributions predicted by PFFEA. It should also be noted that because PFFEA is a finite element based method, PFFEA models can be generated directly from an existing finite element model, with only a small amount of additional information supplied by the user.

In its present configuration, the PFFEA software system is now capable of analyzing relatively complex structural models. The software consists of the finite element program VASTF, a translator program used for converting a VAST finite element model to a PFFEA model (which can then be run on VASTF), and a post-processing program POSTPF that converts VASTF output data into various physically meaningful forms.

In previous phases of the PFFEA development, a hybrid energy method was developed for predicting high-frequency radiated sound power from a vibrating surface. This method was based on a number of simplifying assumptions related to the way vibrating plates interact with an adjacent fluid and the energy and intensity patterns that result. Unfortunately, the validity of this approach has of yet not been thoroughly validated. As a result, it has been proposed that the sound modeling algorithms developed for AVAST be used as a form of post-processor for the PFFEA code. In the discussion to follow, a strategy for linking AVAST and PFFEA is presented.

4.1 Linking AVAST and PFFEA

After reviewing both the input data requirements and the output generated by the PFFEA code, it became clear that the input geometric data (stored on the file having the extension "gom") and the computed estimates for velocity, (written to a file sharing the same prefix but assigned the extension "pfa") could be used as input to an AVAST transducer analysis. A transducer problem, at its commonly referred to in the acoustics literature, suggests a situation where the velocity on the surface of the radiating structure is known but the surface pressure is not. Fortunately, AVAST has algorithms appropriate for use in cases involving transducer-type boundary conditions. As a result it is proposed that a translator, which could convert PFFEA geometric data and structural velocities into an AVAST compatible formats, be developed to act as a link between PFFEA and the sound modeling algorithms currently available in AVAST.

In order to demonstrate the potential of this approach, a PFFEA/AVAST translator was developed. The translator has been coded as part of the AVAST GUI. User's can access the translators when opening a PFFEA file (see Figure 4.1). Once the user has selected the file prefix, AVAST searches for files matching that prefix and having the extensions "gom" and "pfa". If these files are available, AVAST will extract both the geometric description of the wet surface and the estimates for structural velocity. The user can then proceed to compute sound pressure levels using the same steps established for a traditional AVAST transducer analysis.

4.2 Example

In order to evaluate this new capability, the PFFEA model described in Chapter 2 of this report was used as a test case. For the purposes of this investigation, the fluid medium was assumed to be air (density = 1.2 kg/m^3 and sound speed = 343 m/s) and the excitation was provided by a shaker located as shown in Figure 2.1 and operating at 6 kHz. The orientation of the field points (located at a distance of 10 m from the center of the cylinder) is shown in Figure 4.2. Sound pressure estimates, in the form of a directivity pattern, are provided in Figure 4.3.

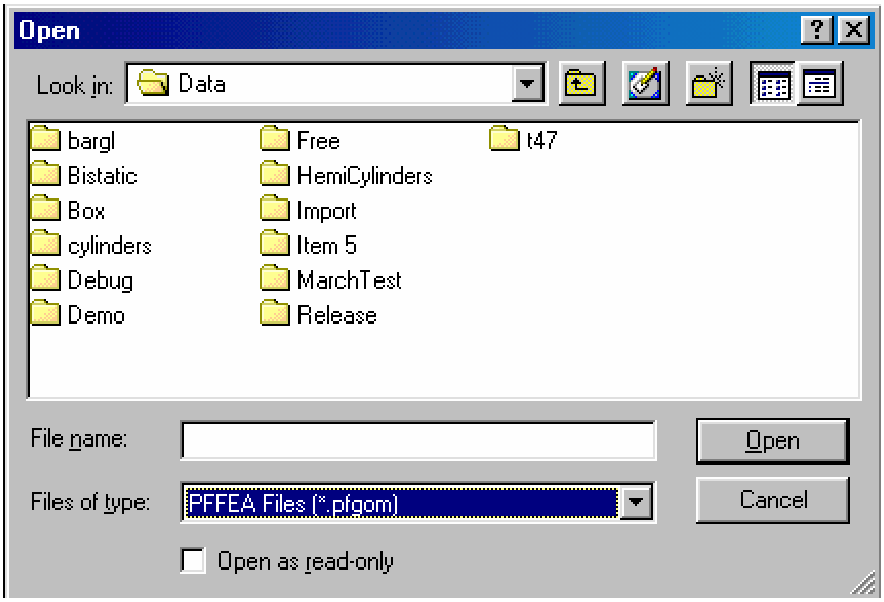

Figure 4.1: Importing PFFEA Models into AVAST

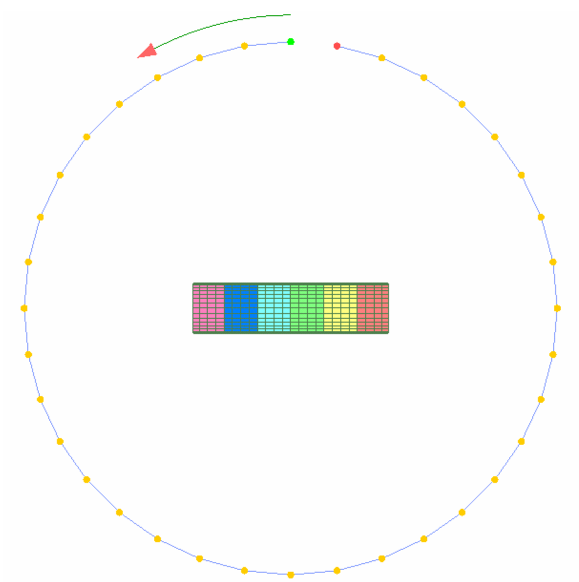

Figure 4.2 Orientation of Field Points (Actual distance of field points is 10m – 4.m as displayed)

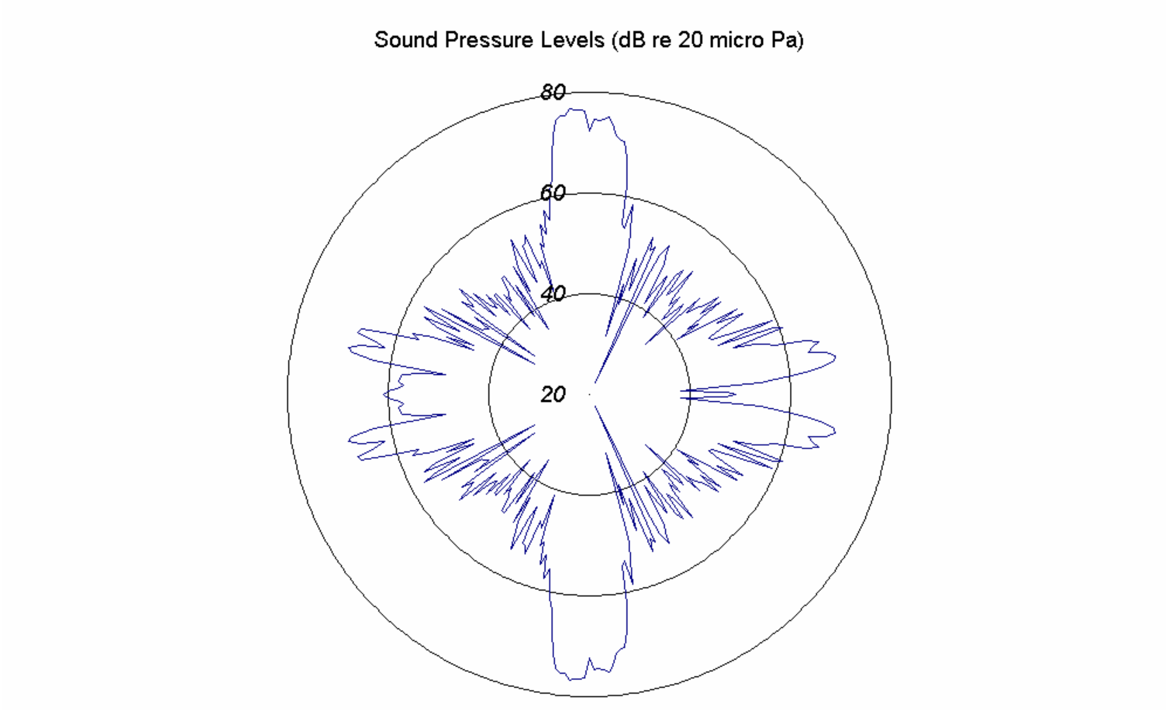

Figure 4.3 Sound Pressure Level Directivity Pattern (Shaker Orientation is aligned with 12 o'clock)

5. References

1. Gilroy, L.E., ”Experimental Investigation into the High Frequency Structural Response of a Ring-Stiffened Cylinder with a Deck”, in progress.

List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence

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power flow
PFFEA
high frequency
radiated noise
cylinder
mobility

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